# GALVANOTROPIC RESPONSES OF PARAMECIA TO BALANCED SQUARE WAVES

JOHN A. MILLER AND LEO S. GOLDSTON
Department of Zoology and Entomology
The Ohio State University

Galvanotropism in *Paramecium* has been extensively studied in respect to many variables. Jennings (1906) reviews the earlier investigations and comes to the conclusion that reaction is due to the reversal of effective ciliary stroke on the cathodal surface of the organism. Bancroft (1906) observed that certain salts when added to the environment will cause forward locomotion toward the anode. Stratkewitsch (1907) observed internal pH changes under direct and alternating current. Scheminsky (1926) and Hausman (1929) discussed movement in varying sinusoidal alternating frequencies. Kamada (1928–31) reported on galvanotropism with controlled "current strength," "salt intensity," and time factors. Much quantitative work has been done in respect to direct, interupted direct, and sinusoidal alternating current of varying frequencies.

The quantitative and qualitative studies made possible by electrical stimulation is fully recognized. In order for electrical stimulation to be of value in quantitative studies it is necessary that the current be constant and any interchange instantaneously opposite. This is possible by the use of a balanced square wave as described by the authors in their previous paper (Goldston and Miller, 1947).

## PROBLEM

In the behavior laboratory, keeping *Paramecium caudatum* in a normal environment, we applied frequency controlled, balanced square waves, the electrochemical results of which were equal and opposite (Goldston and Miller, 1947). In keeping all other factors constant except frequency of polarity interchange, we observed the reactions of paramecia subjected to frequencies from zero to one hundred thousand cycles per second.

## APPARATUS

The method for production of balanced square waves was discussed by the authors in a previous number of this *Journal.* The electronic wave form made available by such mechanisms was found to be applicable to studies in protozoan behavior.

The electrodes were introduced into the ends of an elongated U-shaped culture tube (see Figure 1). A constant plane-to-plane voltage of 45 volts was applied to the culture which approximated 200,000 ohms resistance at all times. This permitted the flow of 0.155 milliamperes. This amperage to which the paramecia were subjected was sufficient to produce definite cathodal galvanotropism without any morphological distortion. Balanced square waves from .25 to 5 cycles per second were produced through the use of the electric dpdt relay. Frequencies from 5 to 100,000 cycles per second were provided by a variable square wave generator.

## APPLICATION

A standard culture of *Paramecium caudatum* was secured for the experiment. The organisms were placed within the U-tube and observed through a binocular microscope. The same culture source was used throughout the experiment with frequent changes of samples. Temperature was kept constant at 21° C. Throughout the range of frequencies studied a consistent sample reaction of almost 100% could be noted.

Upon the application of a direct current an almost 100% cathodal movement was noted. The morphology of the individuals was normal. With an instantaneous interchange of polarity, there was an immediate orientation toward the new cathode (see Figure 2).

When the frequency of polarity interchange occured at intervals of two seconds, individual paramecia in following the cathode traversed an ellipse (see Figure 3).

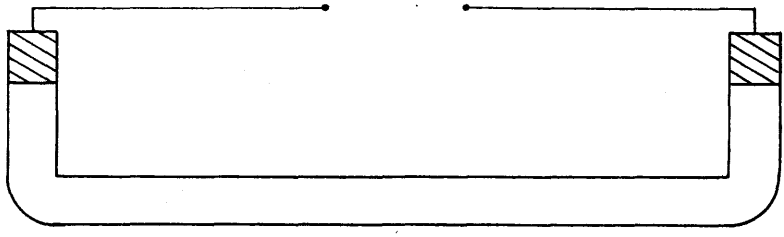

FIG.1

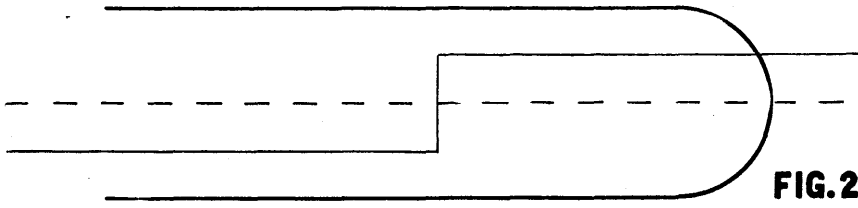

FIG.2

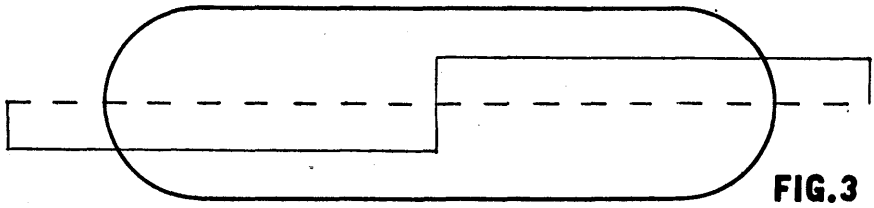

FIG.3

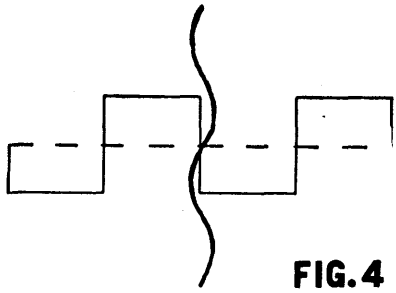

FIG.4

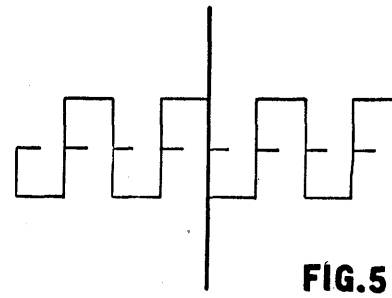

FIG.5

FIGURE 1. Culture tube used in observation.

FIGURES 2–5. The paths taken by Paramecia in response to electronic stimulation in relation to the frequency of the balanced square waves. The orientation to a new direction in each instance starts at the point of polarity interchange (not illustrated). See text for details.

Increasing the frequency of polarity interchange to 0.9 seconds resulted in mass movement at right angles to electron flow. The course followed by individuals when subjected to the above frequency was slightly sinusoidal in relation to the tempo of interchange (see Figure 4).

At frequencies of three cycles per second, the general movement continued to be at right angles to current flow, slow forward locomotion was observed with the exception of a few individuals which remained stationary rotating on their long axis.

At a frequency of ten cycles per second a rather smooth path was followed at right angles to the current flow (see Figure 5). Movement was somewhat faster and there was some individual pin-wheeling. Paramecia continued to respond in a like manner throughout the range to five hundred cycles per second. During this change in frequency, individuals were observed to approach normal locomotor speeds. At the upper limits of the range a few individuals were noted to move parallel to current flow for short distances.

From 500 to 1080 cycles per second, the frequency was increased in steps of sixty cycles. The behavior at 1020 was essentially the same as that observed for 500 cycles per second. At 1080 cycles per second perfectly normal behavior was observed. There being no change in behavior between periods when electronic stimulation of this frequency was applied, and when all electronic stimulation was removed. The behavior of the paramecia which appeared to all intent to correspond to the normal behavior at 1080 cycles per second was not altered through further increases in frequency to 100,000 cycles per second.

## SUMMARY

Paramecia exhibit definite cathodal galvanotropism when subjected to direct current at low amperage. When stimulation is in the form of balanced square waves, the electro-chemical results of which are equal and opposite, and varying only the direction and duration of electron flow, the organisms were observed to alter their reactions in response to frequency variation.

At the lowest range of frequencies tested, paramecia move parallel to electron flow, reversing direction upon polarity interchange, thereby travelling in an elongated elliptical path, the long axis of which is parallel to electron flow.

Increasing frequency of polarity interchange shortens the long axis of the elliptical path, finally reaching a point where both axes are equal and the path is circular.

Increasing the frequency of polarity interchange beyond this point and up to 1080 cycles per second paramecia traverse a path at right angles to electron flow. At 1080 cycles and beyond there is no discernable difference in behavior between paramecia subjected to the current and paramecia in the normal culture.

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